Performance effects of display incongruity in a digital and analog clock reading task

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INTRODUCTION

In an era of increasing automation, it is important to design displays and input devices that minimize human error. In this context, information concerning the human response to the detection of incongruous information is important. Such incongruous information can be operationalized as unexpected (perhaps erroneous) information on which a decision by the human or operation by an automated system is based. In the aviation environment, decision making when faced with inadequate, incomplete, or incongruous information may occur in a failure scenario.

An additional challenge facing the human operator in automated environments is maintaining alertness or vigilance (Comstock, Harris, and Pope, 1988). The vigilance issue is of particular concern as a factor that may interact with performance when faced with inadequate, incomplete, or incongruous information. From the literature on eye-scan behavior we know that the time spent looking at a particular display or indicator is a function of the type of information one is trying to discern from the display (Harris, Glover, and Spady, 1986). For example, quick glances are all it takes for confirming that an indicator is in a normal position or range, whereas a continuous look of several seconds may be required for confirmation that a complex control input is having the desired effect. Important to consider is that while an extended look takes place, visual input from other sources may be missed. Much like an extended look, the interpretation of incongruous information may require extra time.

The present experiment was designed to explore the performance consequences of a decision making task when incongruous information was presented. For this experiment a display incongruity was created on a subset of trials of a clock reading laboratory task. Display incongruity was made possible through presentation of "impossible" times (e.g. 1:65 or 11:90). Subjects made "same" "different" decisions and keyboard responses to pairings of Analog-Analog (AA), Digital-Digital (DD), and Analog-Digital (AD), display combinations. For trials during which display incongruities were not presented, based on prior research (Miller and Penningroth, 1997) comparing digital and analog clock displays, it would be expected that the Digital-Digital condition would result in the shortest response times and the Analog-Analog and Analog-Digital conditions would have longer response times. The performance consequence expected on trials with incongruous times would be very long response times.

METHOD

Subjects

Twenty university students participated in the experiment. The median age of the subjects was 21.5 years, and there were 10 male and 10 female subjects. All subjects reported normal or corrected to normal vision. Subjects were paid for their participation in the experiment.

Apparatus and Stimuli

The time comparison task consisted of a left and right time display presented simultaneously on the CRT screen. The time displays could be both digital, both analog, or a combination of the two. When digital, the displayed times were digits one cm in height showing the hour and minutes (e.g. 9:30), and were based on a twelve-hour clock. The distance between the center of the left and right time display areas was 10.5 cm. The font was a modified bold arial with serifs on the numerals "1" and "7". When analog, a round clock-face was displayed with a 7.7 cm diameter round dial with hands showing the hour and minutes. The long hand was 4.4 cm (3.6 cm from center) and the short hand was 2.5 cm. These hands were tapered with a maximum width of approximately 0.25 cm near the center of the clock face. Twelve large tick marks were shown at each hour position and smaller tick marks were shown at the minute increments. Numerals were not displayed on the analog clock face. The digital time display numerals were white. The analog clock face and tick marks were yellow and the clock hands were white. The background for the entire screen was dark gray. The time displays were presented on a 35.56 cm (14 inch) diagonal Magnavox VGA computer monitor at a screen resolution of 640 X 350 pixels. Viewing distance (subject to monitor) was about 46 cm. The software generating the stimuli and recording response times and accuracy was running on a Compaq 386-20 desktop computer.

Procedure

Once seated in front of the computer monitor, subjects were shown examples of the analog and digital time displays. Then instructions for the "Time Display Comparisons" task were presented both on screen and verbally by an experimenter. The instructions stated that "The task you are about to begin will present two Time Displays near the center of the screen." "You should press the **S** key if the times shown are the Same, or the **D** key if the times shown are Different." There were a total of 96 trials with an intertrial interval of about three seconds. Prior to each new time display comparison a countdown digit at the center of the screen signaled two seconds and one second before the next presentation. This was included to direct attention to the center of the screen which would otherwise have been blank between presentations.

All displayed times, for both digital and analog presentations, were in even five minute increments (e.g. 2:10 or 1:35, never 1:32). Display incongruity was made possible through presentation of "impossible" times (e.g. 1:65 or 11:90). Display incongruities were present on 16 of the 96 trials in the Digital-Digital, Analog-Digital, and Digital-Analog conditions. Subjects were not briefed on the possibility of seeing "impossible" times because responses to incongruous or unexpected information was one of the foci of the study.

RESULTS

The initial analyses addressed differences between the analog and digital display conditions when no incongruity trials were present. As illustrated by the mean response times (RT) shown in Figure 1, the Digital-Digital display condition RT is significantly shorter than for the Analog-Analog display condition ($F(1,18)=13.49$, $p<.01$). In addition, the cases in which the displayed times were different in each of these display conditions resulted in significantly longer RTs ($F(1,18)=10.87$, $p<.01$). As can be seen in Figure 1, these longer times for detecting a "different" condition did not carry over to the Analog-Digital condition where still longer RTs were found. Since there were no differences found or expected between Analog-Digital and Digital-Analog conditions (swapping of positions left and right) the results from both of these conditions are reported as the Analog-Digital condition. As would be expected, the Analog-Digital

condition did reflect significantly longer RTs than the Analog-Analog condition ($F(1,18)=33.91$, $p<.01$). Analyses by subject gender showed no differences in RT in any display condition.

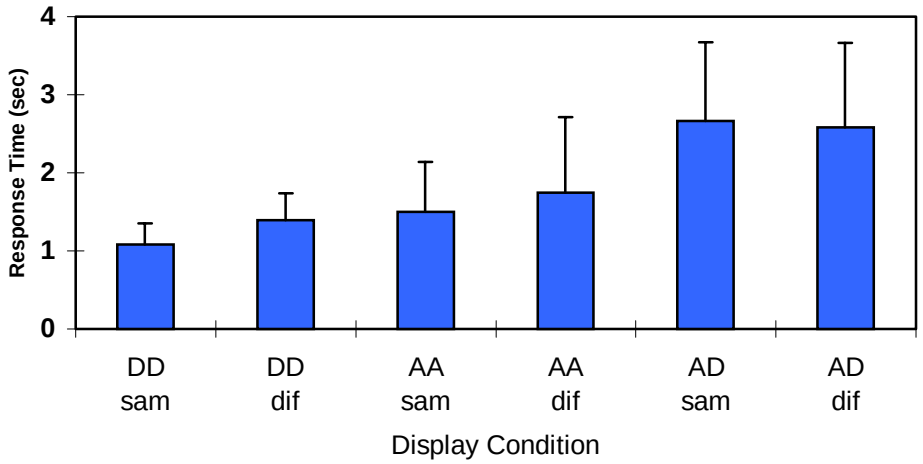

Figure 1. Response Time and St. Dev. by display condition (sam=same, dif=different).

The RTs for the first five Analog-Digital incongruity trials are shown in Figure 2. As would be expected, these RTs showed a much longer (slower) response time (a mean of over 4 seconds) to the initial incongruity exposure (Trial 11).

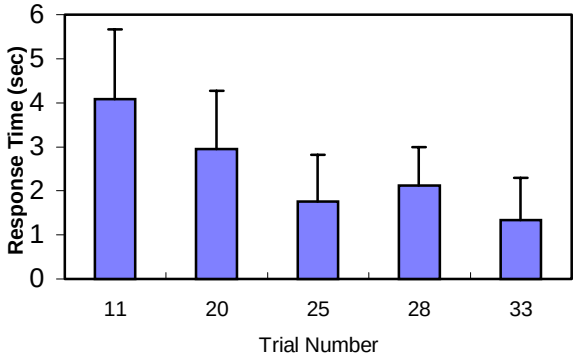

Figure 2. Response Time and St. Dev. on Analog-Digital Incongruity Trials.

These incongruity trials differ significantly ($F(4,85)=15.08$, $p<.01$), and Duncan post hoc tests ($p<.05$) showed a significant difference between trials 11 and 20 and between these two and subsequent incongruity trials. As can be seen in Figure 2, subsequent incongruity trial response times gradually began to look like standard trials as these trials were no longer viewed as incongruous to the subjects.

Incongruity trials were also presented in the Digital-Digital condition. These trials did not result in the very long RTs associated with the Analog-Digital condition. Perhaps this is because the subject could do a simple pattern match as opposed to the mental transformation required when comparing the analog and digital displays. There were no Analog-Analog incongruity trials in this experiment because of the way the incongruity trials were generated.

DISCUSSION

The present experiment showed that the shortest response times were found for "same / different" comparisons made for Digital-Digital time displays for young (median age 21.5) subjects. Significantly longer RTs were found for Analog-Analog comparisons, and still longer times for Analog-Digital comparisons. The longer RTs for the Analog-Digital case are most likely explained by additional mental

operations involved in conversion of one of the two times before the "same / different" judgement can be made. In the case of the Digital-Digital or Analog-Analog comparisons a rapid pattern match would be all that was needed. The additional time required of the analog display condition may reflect the added complexity of the clock-face and hands relative to the simple digital numbers.

Trials containing an "incongruity" consisting of an "impossible" time on the digital side of the Analog-Digital pairing resulted in markedly longer RTs. As subjects saw subsequent presentations of these anomolous cases the RTs gradually became shorter. It is interesting to note the length of the initial incongruity RTs. The means exceeded four seconds. In this experiment there were no other tasks to perform therefore long decision times did not have a penalty with regard to other tasks. It would be interesting to explore incongruities in a multitask environment where long RTs on one task would negatively impact other tasks.

The present experiment, although using a different type of discrimination task, confirms the findings of Miller and Penningroth (1997), and showed that in general digital display comparisons were done more quickly by the young subjects used in both studies. It would be interesting to conduct the same analog and digital display condition experiments with older subjects whose early clock reading experience was all with analog clocks.

In the present experiment all incongruity trials consisted of an "impossible" time on one of the digital time representations on selected trials. It is possible to create an analog incongruity in future experiments by reducing or eliminating the length difference between the long and short hands on the clock face. In cases in which clock hand length discrimination is made more difficult, longer response times and increased error rate would be expected.

The importance of the findings of this experiment are threefold: (1) display incongruity can be created in a laboratory task environment, (2) much more time is required for subjects to process an unexpected incongruity, and (3) there is a time cost for comparisons made in which mental conversions are required, as in the Analog-Digital and Digital-Analog pairings in the present experiment. While all information was presented visually in this study, the latter finding concerning mental conversion or transformation of information has wider implications. One such case would be detection of errors when pilots receive air-traffic-control information aurally but this information is entered and checked visually.

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